ditioning. The task of applied science is to find out the best elements in a natural environment and to select the good without the bad.

Only as we succeed by the application of the methods of research in disentangling and measuring the various factors involved in atmospheric influence shall we be able to establish sound standards for the practical art of ventilation.

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SOME ENGINEERING PROBLEMS IN VENTILATION

In the study of ventilation the engineering problems have not been overlooked. The criticisms directed against artificial ventilation have accomplished the double purpose of spurring to greater effort those who have been investigating the physiological problems relating to this subject and of causing the ventilating engineer to investigate the mechanical features of his work, with the intent of determining whether ventilation systems as installed meet all of the demands of good ventilation as now understood and whether they operate at a maximum of mechanical efficiency.

A careful review of the results in both fields is of surprising interest. The sanitarian formerly told us that carbon dioxide was a poison, that insufficient ventilation meant insufficient oxygen for breathing purposes and that we were endangered by "crowd poison" when in a mass of people. But little was said of temperature, less of humidity and nothing of air movement. We all believed that the chemistry of the air was vital.

The sanitarians, as a result of much experimentation, beginning about ten years ago, have proven to the satisfaction of all that there were other factors within the realm of ventilation of much greater importance than the chemistry of the air, notably its temperature, humidity and air movement, that is, the physical condition of the air.

The effect of excessive temperatures and humidities is especially well understood, as is the demand for constant air movement for the elimination of bodily heat and moisture. Less is scientifically known of the effect of cold and the effect of low humidities. The solution of these two problems is of vast importance.

Some there are who disregard altogether air quality, pinning their entire faith on proper temperature, humidity and air movement. Such a position is not justified by any reliable data now available. The cumulative effect of long exposures to stagnant air must be studied before safe conclusions may be drawn. Attention may be directed to the fact that in the experiments of the New York State Commission on Ventilation stagnant air decreased the appetite of the subjects 13 per cent. Is it not safe to assume that this is indicative of other, and possibly more serious, results. The report of Professor Winslow on the first year's work of the commission well states that this is "an observation which for the first time offers scientific evidence in favor of fresh air as compared with stagnant air of the same temperature and humidity." A final determination of the importance of air quality involves extended experimentation.

Window ventilation has been put forward as a panacea for all of ventilation's ills. But how little we scientifically know of its worth or its difficulties, especially those of air distribution, drafts, stagnant areas, temperature regulation, humidification, dust and economics.

But real advances have been made in solving the long-standing question of what constitutes good ventilation. The solution

of the remaining problems is but a matter of brief period. Coincidently, splendid advances have been made in working out the mechanical problems of ventilation. The details of the installation of the boiler plant have been refined with a resulting increase in the efficiency of operation. New methods of steam distribution, such as the vapor, modulating and vacuum systems, have produced added comfort and economics. Temperature control systems have been devised and perfected to a point of reliability and durability. The individual duct ventilating system, providing air in the volumes and of the exact temperature required by each individual room under varying weather and other conditions, has been developed. Greater attention is paid to the diffusion of the ventilating air. More attention is now paid to the character of the installation and the materials used therein. Also much emphasis is being placed upon the measure of intelligence exercised in the operation of the plant, upon which both efficiency and economy depend. More effort, however, still needs to be made in these last two directions. Noisy heating and ventilating plants may be considered a thing of the past, for noise is indicative only of lack of skill in design or installation.

Ten years ago the mechanical efficiency of the ventilating fan customarily used was about 45 per cent. Now the best type of fan (the multi-blade) has an efficiency of 65 per cent. This advancement results in the saving of more than 30 per cent. of the power expenditure for ventilation. The efficiency of the driving device has also been increased, although in a less degree.

Possibly the most interesting, important and valuable recent addition to the equipment of ventilating plants is that of the air washer. Reference to air washing is made by Dr. D. B. Reid in his book on "Ventilation" published in London in 1844 but it is really a product of the last ten years. Briefly it consists of a sheet-metal chamber in which the air is passed through a heavy mist and then through baffles or eliminator plates by which the air is so deflected that the entrained moisture is removed. The base of the washer constitutes a tank, into which the spray water falls and from which it is drawn by a centrifugal pump, usually motor driven. The pump forces the water through pipes and so-called nozzles which atomize the water in the spray chamber of the washer.

The manufacturers of these washers customarily guarantee the removal of 98 per cent. of the dust in the air. Practically all of the larger dust particles are removed but there is always a residue of fine dust which no washer will remove. In dry windy weather when there is a great deal of dust in the air, a large percentage of the dust is removed, but when there is very little dust in the air, as after a heavy rain, a small percentage of the dust is removed. Thus in Mr. M. C. Whipple's studies of the air washer it was found that the dust removal varied from 64 per cent. to 7 per cent. Certain dusts are not, to an appreciable extent, removed by the air washer. A standard method of testing air washers is needed and efforts are being made by the American Society of Heating and Ventilating Engineers to work out this problem.

The best results obtained in artificial humidification have been through the medium of the air washer. By the use of thermostatic devices an accurate control of the degree of humidification is obtained. The use of the evaporating pan containing a steam coil placed in the fresh-air chamber, the coil being under thermostatic control, also makes possible artificial humidification, but less satisfactorily.

The air washer may also be used for air

cooling. The evaporation of the water in the spray chamber will result in a lowering of the temperature of the air to the extent of 75 per cent. or more of the difference between the wet and dry bulb temperatures, often amounting to 10 to 15 degrees and sometimes to 18 to 20 degrees. This is due to the fact that water can not be evaporated without a supply of heat from some source, and in this case the heat is taken from the air. Considerable cooling can be done by the use of the same water recirculated by the pump and a greater degree of cooling may be accomplished by a continual supply of cold water. Purchased from the city mains this would be expensive, but if pumped from an artesian well the cost is small. Where a constant cooling effect is desired, independent of weather conditions, the use of a refrigerating plant in combination with the washer is necessary. The water tank is then increased in size and brine or ammonia coils, partially submerged and partially subjected to the falling spray, are installed. This is the most efficient method of positive artificial cooling, and is the most desirable method for ordinary purposes. Unfortunately it is expensive to install, involving approximately $300 to $600 per thousand cubic feet of air cooled. The cost of operation altogether depends upon the nature of the plant of which it is a part. If the plant is large, with exhaust steam to spare for use in an absorption refrigerating machine and the cooling water used in connection with the refrigerating plant may be used in the boilers and for domestic purposes in the building, the cost of operation is slight. Otherwise it may be roughly stated that the cost of cooling ten degrees during the summer is approximately equal to the cost of heating seventy degrees during the winter.

Cooling by evaporation of water alone has the disadvantage of increasing the humidity, which is usually considered objectionable. But there is some evidence that in hot weather the lower temperature with higher humidity is preferred by workers. Mr. J. I. Lyle quotes, among others, an engineer who has done a great deal of testing laboratory work, in which the conditions were most exacting. He writes:

> We can state that under the conditions shown by the readings below, the inside condition with a lower temperature, but a higher humidity, is more pleasant than the outside condition with higher temperature and lower humidity.

He illustrated by a comparison of outside conditions of 90 degrees dry bulb, 80 degrees wet bulb and 65 degrees relative humidity with inside conditions of 85 degrees dry bulb, 79 wet bulb and 77 per cent. relative humidity.

For ordinary ventilation work cooling at the expense of an increased humidity has been regarded as objectionable. It is said to produce a moist "clammy" feeling. Thus dehumidification becomes a part of artificial cooling, and the most expensive part, for the air must be cooled to that temperature at which saturated air contains the moisture necessary to give the desired relative humidity in the air when reheated to the ultimate temperature.

The use of the air washer has become almost indispensable in many industries, such as textile manufacturing, candy, macaroni, photographic and film making and in some processes of paper, tobacco, chemical, steel and plumbing fixture manufacturing.

Commercial considerations have done much to develop the use of the air washer in industrial fields. It is regrettable that humane considerations have done much less in this way in the general field of ventilation.

Possibly the most interesting study in the mechanics of ventilation is that of the

recirculation of the air used for ventilation. The New York State Commission on Ventilation, established through the generosity of Mrs. Elizabeth Milbank Anderson, has been actively interested in this work, and worthily so, for should it prove practical the cost of ventilating would be materially reduced. At one of the first meetings of the commission arrangements were made to carry on research work in this field. It was found that experiments along this line had been conducted by Dr. J. H. McCurdy, at the International Y. M. C. A. College Gymnasium, at Springfield, Mass., and at the Jackson School, Minneapolis, by Professor Frederic Bass. With the direction and support of the commission both of these experiments were continued under improved conditions.

In the former case use was made of the plant installed for ventilating the building, which was readily adaptable to the purpose.[1]

This system included motor-driven supply and exhaust fans, heaters and an air washer of 36,000 to 40,000 cubic feet per minute capacity, or over 300 cubic feet per minute per occupant. It is such a system as is usually used for ventilating such buildings, and not an experimental plant, except that the volume of air used was larger than usual. By the manipulation of dampers the air could be supplied entirely from out-of-doors air, the air could all be recirculated or part outdoor air and part recirculated air could be used. The air could be washed or not, as desired. Experiments were made under all of these conditions, the subjects being the college students at exercise in the gymnasium, usually about 70 in number.

The carbon dioxide content of the air, the humidity and the temperature were carefully studied. Also studies of the efficiency and results of air washing were very carefully made by Mr. M. C. Whipple, of Harvard University.

The conclusion was reached that there seemed to be no appreciable difference between washed recirculated air and outdoor air similarly treated so far as bodily comfort is concerned. Naturally the proportion of carbon dioxide is greater when using the recirculated air, but no significance is attached to this fact. Mr. Whipple concludes "that recirculation provided a plentiful supply of air with no apparent sacrifice of wholesome properties, and that it is a safer source of supply than outside unwashed air."

During the winter of 1913–14 further studies were made at Springfield under the direction of the Ventilation Commission, the results obtained from recirculated air being equally as satisfactory as those obtained from the use of outdoor air. Window ventilation failed to give satisfaction.

Odors were not noticeable to those occupying the room during the use of recirculated and washed air, although sometimes barely noticeable to one entering from out-of-doors.

Conclusions were based upon the results of physiological examinations and comfort votes of the students.

In the second case a special plant was installed for one room of the school building, the pupils in the room serving as subjects. The air was introduced into the room at the top of each desk through a 2-inch vertical riser from a duct below the floor, emerging through a funnel-shaped, nearly horizontal orifice, at a velocity which was barely perceptible at a distance of two feet from the opening.[2] Air was also introduced at the top of the blackboards at the ends of the room. The air was exhausted through fifteen 3-inch openings evenly

[1] Described by G. F. Affleck in *Am. Phys. Educ. Review*, April and June, 1912.

[2] Described in paper read by Professor Bass before Am. Soc. H. and V. Engineers, July, 1913.

spaced at the ceiling of the room, and after being passed through an air washer, where it was cooled by the water about 15 degrees, it was returned to the room. The volume of air thus recirculated averaged 8.9 cubic feet per minute per pupil.

The results obtained in this room were compared with results in a room in the Adams School, the pupils in both rooms being of the same age, grade and general condition. The room in the Adams School was ventilated as is usual in the case of schoolrooms. The air was admitted through one opening above the blackboard and was exhausted through one opening near the floor on the same side of the room. The air was not washed and the volumes averaged 35.4 cubic feet per minute per pupil. The temperature averaged slightly lower and humidity slightly higher in the Jackson schoolroom.

The carbon dioxide averaged 12.5 parts per 10,000 in the Jackson School and 9.1 parts per 10,000 in the Adams School.

Dust counts showed 105,000 particles per cubic foot of air in the Jackson School and 225,000 in the Adams School. As a result of these experiments, covering a period of four months the conclusion is offered that

> it is impossible to demonstrate physical or mental deterioration due to the use of recirculated air. Neither is it possible to ascribe any discomfort on the part of the pupils or the teacher to this recirculated air.

The air washing, it is stated, was not sufficient to remove all odors, but they were reduced to such an extent that they were not offensive to persons occupying the room continuously, although noticed by persons entering the room.

In this experiment the problem of the use of recirculated air was combined with that of the use of a reduced volume of air delivered directly toward the face of the pupil. The two problems should be separately studied. More light on the effect of recirculated air is desirable, as is the case with reduced volumes of air directly delivered and generally distributed.

In the case of one of these experiments the volume of air used was more than ten times that customarily used for ventilating purposes, and in the other case the volume of air used was less than one third that ordinarily used. Experiments with the standard and other volumes of air with the standard and diffused methods of introduction are desirable.

Studies along these lines are planned by the Ventilation Commission in connection with its experimental plant in Public School No. 51, the Bronx, New York City.

The economy of air recirculation was presented by the writer in the *Am. Physical Education Review* of December, 1913. Very marked economy was credited to recirculation. This claim was disputed by Evans in the June issue of the *Heating and Ventilating Magazine,* the claim being made that the cost of fresh cold water required for cooling and dehumidifying the recirculated air offset the saving in heat. Actual experience proves that such is not the case. Professor Bass states that water cost three cents per day during his experiments, which is vastly less than the amount stated by Evans. Dr. McCurdy states that some water was used for cooling, but even with 40,000 cubic feet of air per minute recirculated the cost of the fresh water used does not appear to have been a serious item.

It is manifest that a large amount of heat is saved, and this certainly warrants the most careful study of the problem of recirculation. Should it prove in every way satisfactory a great step in advance will have been made in the field of mechanical ventilation. But it may not be recommended as yet.

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